TOPOLOGICAL TRANSITIVITY OF COMPACT ACTIONS ON C*-ALGEBRAS

SA GE LEE AND SUN YOUNG JANG

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ABSTRACT. We give some conditions under which minimality is equivalent to the other notions in noncommutative ergodic theory and prove that in a compact C*-dynamical system topological transitivity is invariant under exterior equivalence.

1. Introduction

Let \((A, G, \alpha)\) be a C*-dynamical system. We shall denote by \(A^\alpha\) the fixed point C*-subalgebra of \((A, G, \alpha)\) and by \(\mathcal{H}^\alpha(A)\) the set of all nonzero \(\alpha\)-invariant hereditary C*-subalgebras of \(A\). In [5], the authors define the C*-dynamical system \((A, G, \alpha)\) as

1. uniquely ergodic if there exists a unique \(\alpha\)-invariant state of \(A\),
2. weakly ergodic if \(A^\alpha\) contains only the scalar element,
3. topologically transitive if for any \(B_1, B_2 \in \mathcal{H}^\alpha(A)\), their product \(B_1B_2\) is not zero,
4. minimal if \(\mathcal{H}^\alpha(A) = \{A\}\).

2. Topological transitivity of compact actions

Let \(A\) be a C*-algebra. For each representation \(\{\pi, H\}\) of \(A\), we denote by \(M(\pi)\) the enveloping von Neumann algebra \(\pi(A)^\prime\)

Lemma 2.1. Let \((A, G, \alpha)\) be a C*-dynamical system. If there exists a faithful representation \(\pi\) of \(A\) such that the induced action \(\hat{\alpha}\) is weakly ergodic on \(M(\pi)\), then \((A, G, \alpha)\) is minimal.

Proof. If \(B \in \mathcal{H}^\alpha(A)\), then \(\pi(B)\) is an \(\hat{\alpha}\)-invariant hereditary C*-subalgebra of \(\pi(A)\). Then by [6, 3.11.10] there exists an \(\hat{\alpha}\)-invariant open projection \(e\) in \(M(\pi)\) such that \(\pi(B) = (eM(\pi)e) \cap \pi(A)\). Since \(\hat{\alpha}\) is weakly ergodic on \(M(\pi)\), \(e\) is the identity of \(M(\pi)\). Since \(\pi\) is faithful, \((A, G, \alpha)\) is minimal.

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Let \((A, G, \alpha)\) be a C*-dynamical system and \(G\) be a compact group with the normalized Haar measure \(dg\). Then the map defined by
\[
x \rightarrow \int_G \alpha_g(x) \, dg
\]
is a conditional expectation from \(A\) onto \(A^\alpha\), denoted by \(P_0\).

**Theorem 2.2.** Let \((A, G, \alpha)\) be a uniquely ergodic C*-dynamical system with a compact group \(G\). Then \((A, G, \alpha)\) is minimal and \(A\) is unital.

**Proof.** Since \(P_0\) is faithful, \(A^\alpha \neq 0\). Every state of \(A^\alpha\) can be extended to an \(\alpha\)-invariant state on \(A\) by the map \(P_0\). Therefore \(A^\alpha\) has only one state \(\omega\), and so \(A^\alpha = Ce\), where \(e\) is the unit of \(A^\alpha\). Put \(\dot{\omega} = \omega P_0\). Then the G.N.S. representation \((\pi, H, \xi, U)\) defined by the \(\alpha\)-invariant state \(\dot{\omega}\) is the faithful covariant representation of \((A, G, \alpha)\) such that \(\pi \alpha_g(x) = U_g \pi(x) U^*_g\) and \(U_g \xi = \xi\) for all \(g \in G, x \in A\). Since \(\dot{\omega}(y^* xe - y^*y) = 0\) for all \(x, y \in A\), we have \((\pi(xe - x)\xi) = 0\) for all \(x \in A\). Since \(\dot{\omega}\) is faithful, \(\xi\) is a separating vector for \(\pi(A)\). Furthermore, since \(\pi\) is faithful, \(xe = x\) for \(x \in A\). By a similar computation we have \(ex = x\). Hence \(e\) is the identity of \(A\). Let \(B\) be an \(\alpha\)-invariant hereditary C*-subalgebra. If we consider the C*-dynamical system \((B, G, \alpha|_B)\), then \(B^\alpha\) have to contain the identity of \(A\). Hence we have \(B = A\).

**Corollary 2.3.** Let \((A, G, \alpha)\) be a C*-dynamical system with a compact group \(G\). Then the following statements are equivalent:

1. \((A, G, \alpha)\) is uniquely ergodic,
2. \((A, G, \alpha)\) is weakly ergodic,
3. \((A, G, \alpha)\) is topologically transitive,
4. \((A, G, \alpha)\) is minimal.

**Proof.** (1) implies (4) by Theorem 2.2. (4) clearly implies (3).

(3) \(\Rightarrow\) (2). Suppose that \((A, G, \alpha)\) is not weakly ergodic. Then there exists a non scalar positive element \(x\) in \(A^\alpha\). We can choose the continuous, real-valued functions \(f(\lambda), g(\lambda)\) in \(C(\text{spec}(x))\) such that \(\text{supp } f(\lambda) \cap \text{supp } g(\lambda) \neq \emptyset\). Let \(B_1\) and \(B_2\) be the \(\alpha\)-invariant hereditary C*-subalgebras generated by \(f(x)Af(x)\) and \(g(x)Ag(x)\) respectively. Then \(B_1 B_2 = 0\).

(2) \(\Rightarrow\) (1). Since \(G\) is compact, \(A^\alpha \neq \{0\}\). Since \((A, G, \alpha)\) is weakly ergodic, we can define a linear functional \(\omega\) on \(A\) by \(P_0(x) = \omega(x)1_A\). Then this is the unique \(\alpha\)-invariant state on \(A\).

**Remark 2.4.** Let \((A, G, \alpha)\) be a C*-dynamical system with a compact group \(G\). If \((A, G, \alpha)\) is uniquely ergodic, then the Arveson's spectrum of \(\alpha\) is equal to the Conne's spectrum of \(\alpha\).

Let \((A, G, \alpha)\) be a C*-dynamical system. If \(\alpha\) is faithful, then we may assume that \(G\) is a subgroup in the automorphism group Aut\((A)\) of \(A\). In this case, we have the following corollary.
Corollary 2.5. Let \((A, G, \alpha)\) be a \(C^*\)-dynamical system. Assume that the subgroup \(G\) in \(\text{Aut}(A)\) has compact closure \(\overline{G}\) in \(\text{Aut}(A)\). Then the following statements are equivalent:

1. \((A, G, \alpha)\) is uniquely ergodic,
2. \((A, G, \alpha)\) is weakly ergodic,
3. \((A, G, \alpha)\) is topologically transitive,
4. \((A, G, \alpha)\) is minimal.

3. Topological transitivity in the perturbed \(C^*\)-dynamics

In [7], the authors showed that two \(C^*\)-dynamical systems \((A, G, \alpha)\) and \((A, G, \beta)\) are exterior equivalent iff there exists a \(C^*\)-dynamical system \((A \otimes M_2, G, \gamma)\) such that

\[
\gamma_t \left( \begin{array}{cc} x & 0 \\ 0 & y \end{array} \right) = \left( \begin{array}{cc} \alpha_t(x) & 0 \\ 0 & \beta_t(y) \end{array} \right) \quad \text{for all } x, y \in A, \ t \in G.
\]

In [3], Bratteli and Elliot defined a notion of topological transitivity that is essentially equivalent to that of Peligard, which we have been using so far. They require that, for each pair of nonzero elements \(x, y \in A\), there exists a \(g \in G\) such that \(x\alpha_g(y) \neq 0\).

Lemma 3.1. Let \((A, G, \alpha)\) be a \(C^*\)-dynamical system. Let \(p\) and \(q\) be equivalent projections in the multiplier algebra \(M(A^\alpha)\) of the fixed point algebra \(A^\alpha\). If the \(C^*\)-dynamical system \((pAp, G, \alpha|_{pAp})\) is topologically transitive, then the \(C^*\)-dynamical system \((qAq, G, \alpha|_{qAq})\) is also topologically transitive.

Proof. Suppose that there exist two elements \(x, y (\neq 0)\) in \(pAp\) such that \(x\alpha_g(y) = 0\) for all \(g \in G\). By Lemma 3.1, there exists \(\alpha\)-invariant partial isometry \(v\) in \(M(A)\) such that \(v^*v = p\) and \(vv^* = q\). Since \(x, y\) are contained in \(pAp\), we have

\[
0 = x\alpha_g(y) = v^*vxv^*v\alpha_g(y)v^*v \quad \text{for all } g \in G.
\]

Since \(v\) is fixed by \(\alpha_g\), for all \(g \in G\) we get

\[
0 = v(v^*vxv^*v\alpha_g(y)v^*v)v^* = qv^*q\alpha_g(qvyv^*q)q.
\]

Put \(x'' = qvxv^*q\) and \(y'' = qvyv^*q\), then \(x''\) and \(y''\) are two nonzero elements in \(qAq\), and \(x''\alpha_g(y'') = 0\) for all \(g \in G\). Hence \((qAq, G, \alpha|_{qAq})\) is not topologically transitive.

Let \((A, G, \alpha)\) be a \(C^*\)-dynamical system with a compact group. In the following we assume that \(A\) is represented nondegenerately, faithfully and covariantly on a Hilbert space \(H\). We denote by \(A''\) the von Neumann algebra generated by \(A\). We denote by \(Z(A)\) the center of some operator algebra \(A\).
Theorem 3.2. Let \((A, G, \alpha)\) be a topologically transitive \(C^*\)-dynamical system and let \(G\) be a compact group. Let \((A, G, \beta)\) be exterior equivalent to the \(C^*\)-dynamical system \((A, G, \alpha)\). If \(Z(A'\beta) = Z(A''\alpha)\), then the \(C^*\)-dynamical system \((A, G, \beta)\) is also topologically transitive.

Proof. Let \((A'', G, \alpha)\) and \((A, G, \beta)\) be \(W^*\)-dynamical systems induced by the \(C^*\)-dynamical system \((A, G, \alpha)\) and \((A, G, \beta)\) due to the covariance respectively. Since \((A'', G, \alpha)\) is ergodic, \(A''\) is finite. As the similar method in Proposition 8.11.5 in [6], we consider the system \((A'' \otimes M_2, G, \gamma)\) obtained from the \(C^*\)-dynamical system \((A \otimes M_2, G, \gamma)\) in the beginning in this section. Put \(p = 1 \otimes e_{11}\) and \(q = 1 \otimes e_{22}\), where \(\{e_{ij}, i, j = 1, 2\}\) is the matrix unit of \(M_2\). Since \(Z(A''\beta) = Z(A''\alpha)\), we have \(Z(A'' \otimes M_2)\gamma = Z((A'' \otimes M_2)\gamma)\). If we consider the canonical central trace of the finite von Neumann algebra \(A''\), then \(p\) and \(q\) are equivalent in \((A'' \otimes M_2)\gamma\). The above result comes from Lemma 3.1, if we consider two \(C^*\)-dynamical systems \((p(A \otimes M_2)p, G, \gamma|_p(A \otimes M_2)p)\) and \((q(A \otimes M_2)q, G, \gamma|_q(A \otimes M_2)q)\).

References


Department of Mathematics, Seoul National University, Seoul 151-742, Korea
Department of Mathematics, University of Ulsan, Ulsan 690-749, Korea